

## **DEEP PLOWING RESTRICTIVE-LAYER SOILS TO IMPROVE IRRIGATION INFILTRATION**

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### **Summary:**

Soil mixing from a one-time deep moldboard plowing 0.4 m deep into a dense clay subsoil increased irrigation intake by 26% and wheat yield by 19%. The increased intake benefits were still present after 25 yr. Annual plowing the topsoil to 0.2 m eliminated surface compaction effects on intake.

### **Keywords:**

**Furrow Irrigation, Furrow Infiltration, Tillage Depth, Water Use Efficiency**

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# DEEP PLOWING RESTRICTIVE LAYER SOILS TO IMPROVE IRRIGATION INFILTRATION<sup>1/</sup>

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## ABSTRACT

Pullman clay loam and related soils are the predominant soil types in the Southern High Plains. They are slowly permeable, but respond to deeper than normal tillage to increase irrigation water intake. A one-time deep moldboard plowing to 0.4, 0.6, and 0.8 m depths was performed in 1966 to evaluate the inversion and mixing of the slowly permeable Bt1 horizon with the Ap horizon. This paper reports long term residual effects from the deep plowing after 25 yr of cropping. Winter wheat was grown during this 4-yr test from 1988 to 1992. After moldboard plowing to 0.2 m to restore surface tillage layer permeability, residual effects from the one-time deep plowing caused an average increase in intake of 26% (129 to 163 mm) for the 0.4 m plow depth and a 40% (52 mm) increase for 0.6 m plowing compared with the 0.2 m check during the first irrigation after tillage. Grain yields were increased from 4.2 to 5.0 Mg/ha (19%) for 0.4 m or deeper plowing. The one-time deep tillage also increased deep soil water storage and apparent crop rooting to extract soil water. Water use efficiencies were about 10% greater for deep plowing treatments.

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## INTRODUCTION

About 40% of the 2 million ha of irrigated soils in the Southern High Plains are slowly permeable clays and clay loams (Musick et al., 1988). Pullman clay loam and closely related soils are the predominate soil types (Unger and Pringle, 1981). About 60% of these soils are irrigated by the graded furrow method. Water intake during furrow irrigation can be relatively high (150 to 200 mm) for the first application after primary tillage. Intake during succeeding seasonal irrigations declines to the 75 to 100 mm range after furrow consolidation. Irrigations are typically applied in 12 to 24 h sets on 400 to 800 m furrow lengths with soil being wetted from 0.6 to 0.9 m deep. Most field crops extract available soil water from 1.5 to 1.8 m in depth.

In order to limit irrigation demand during the major water use periods, deep-profile soil water storage is useful to meet transpiration demands and to reduce adverse water deficit effects on yield. The Pullman soil profile can store about 250 mm of available soil water for extraction by winter wheat to the 1.8 m depth. Starting the season with a wet soil profile is very important for obtaining relatively high wheat yields with limited irrigation water supplies. This effect is illustrated for winter wheat by Musick et al. (1994). Deep tillage of slowly permeable clays can increase deeper soil profile wetting, and can be particularly effective for maintaining yields on the lower sections of graded furrow fields where intake opportunity time is less.

Hauser and Taylor (1964) reported that disk plowing Pullman soil to the 0.6 m depth in 1958 increased water intake during the first 10 h by about 1.9 times, averaging 64 mm with deep plowing. Eck (1986) reviewed the effects of vertically mixing the Pullman soil profile [Profile modification (PM)] to 0.9 and 1.5 m depths using a trenching machine. Alfalfa and grain sorghum responded with increased production and WUE, but wheat production response to PM was small and did not justify costs. Unger (1993) reported that irrigation infiltration and wheat plant rooting were still increased by the PM treatments after 25 yr, although wheat yields were not significantly increased.

The deep tillage treatments reported in this study were performed as a one-time deep moldboard plowing in 1966 to 0.4, 0.6, and 0.8 m on Pullman clay loam at Bushland, TX. Initial results from the tillage and irrigation tests were reported by Schneider and Mathers (1970), Mathers et al. (1971), and Musick and Dusek (1975). Musick et al. (1981) reported results after 13 yr. This paper reports long-term residual effects (after 25 yr) on irrigation water intake resulting from deep

tillage for a slowly permeable clay soil. Deep tillage effects were compared with a conventional tillage check where tillage depth did not exceed 0.2 m.

## PROCEDURE

The Pullman soil profile at the study site has a dark brown clay loam Ap horizon to about the 0.15 m depth, which is also the zone penetrated by most tillage operations. The Bt1 horizon is a dark brown clay extending from 0.15 to 0.4 m in depth, and is underlain by a reddish brown clay to 0.75 m deep. The Bt horizon has a angular blocky structure with bulk densities of 1.5 to 1.6 Mg/m<sup>3</sup>. When dry, the soil develops shrinkage cracks that result in a relatively high initial water intake rate. After initial filling of cracks or saturation of a loosened surface tillage layer, intake rates decline to the basic rate after 2 to 3 h of graded furrow irrigation.

The long-term residual effect of deep moldboard plowing in 1966 was tested on duplicated main plots 12.2 by 300 m during 1988 to 1992 by cropping to winter wheat. Plots were moldboard plowed to the 0.2 m check treatment depth near September 1 in 1988, 1990, and 1991. In 1989, tillage was by multiple disking because the soil was too wet for timely moldboard plowing. In each year, 1.0 m spaced bed-furrows (300 m length) were formed after disking and applying fertilizer at 145 kg/ha N in the form of anhydrous ammonia. Furrow grade was 0.75%. Seeding of TAM 200 wheat was by double-disk opener grain drill in 20 cm spaced rows that resulted in 3 rows per bed and 2 rows per furrow. Seeding rates were 0.67 Mg/ha.

Irrigation was applied through gated pipe and measured with a propeller meter with flow to individual furrows adjusted volumetrically to 0.63 L/s. The relatively low furrow stream size was selected because of the grade, low permeability, and a relatively short furrow length. Duplicate runoff measurements were made from four furrows per plot with individually calibrated H-flumes equipped with FW-1 water stage recorders. Two of the four furrows for runoff measurement had wheel traffic. Runoff was allowed for 4 to 6 h. A commercially available PC computer interface "digitizing tablet" was used to determine water stage heights on flume runoff hydrographs, from which flow volumes were calculated.

Soil water contents were measured gravimetrically by 0.3 m increments to the 1.8 m depth at the beginning and end of season and before and after selected irrigations. Seasonal water use was determined by the water balance method

using beginning and end of season soil profile water contents, net applied irrigation, and precipitation. Wheat yields were determined with a plot combine. Grain yields were adjusted to 13% moisture, w.b. Water use efficiency (WUE) was determined as the ratio of grain yield to seasonal ET (including net irrigation). Treatment means were tested for statistical significance using Statgraphics<sup>1</sup> (1992) for analysis of variance.

Irrigation water intake was also measured by flowing furrow infiltrometer (Dedrick et al., 1985) after moldboard plowing to 0.2 m, disking, bedding, and planting in the fall of 1990. The flowing furrow infiltrometer permitted measuring intake rate and cumulative intake effects from deep plowing under more controlled conditions and to partition the effects of furrow wheel traffic. Infiltrator tests of 8 h duration were made in blocked 4.5 m length sections of furrow.

## RESULTS

### *Seasonal Precipitation*

The cumulative growing season precipitation for the three complete crop seasons is presented with the long-time average for comparison in Fig. 1. This graph illustrates the distribution as well as quantity of precipitation. The 2nd and 3rd crop yr were below average in precipitation, and the 4th yr was about 70% above average.

### *Irrigation Water Intake*

Dates of irrigation applications are presented in Table 1 and irrigation intake for each application is presented in Table 2. For discussion herein, the four crop seasons 1988-89, 1989-90, 1990-91, and 1991-92 will be referred to as years 1, 2, 3, or 4, respectively. The term "plow depth" refers to the depth of moldboard plowing of the original deep plowing treatments in 1966. In each year of this study, the residual effect from deep loosening and mixing of the A and Bt1 soil horizons in 1966 resulted in increased water intake, especially for the pre-season irrigation after primary tillage in early fall. The residual deep tillage effect on intake was limited to 0.6 m, as evidenced by tillage to 0.8 m having no additional effect in any year. For the spring (seasonal) irrigations, the effects of deep tillage were reduced substantially because of surface soil consolidation but were still evident. In yr 2 when fall tillage was limited to disking to only 0.12 m in depth, the effect

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<sup>1</sup>The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

of initial plow depth on intake was less than in other years when plots were fall moldboard plowed to the 0.2 m depth of the check. Pre-season irrigation intake for the 0.4 m plow depth treatment averaged 163 mm or 27% higher than for the 0.2 m check at 129 mm.

Soil water content with depth before and after the preplant irrigation on 14 September 1988 is presented in Fig. 2. A 125 mm rain occurred immediately after the irrigation and before soil sampling could be done so the depth of gravimetric sampling was extended to 3 m to determine the extent of deep profile wetting from the irrigation and rainfall following irrigation. On the deep moldboard plowing treatments that extended to 0.4 m or more in depth, deep profile soil water storage occurred within the 1 to 2.3 m depth. The sharp increase in soil water content with depth from about 1.3 to 1.7 m (Fig. 2) is associated with the beginning of a caliche layer containing varying amounts of  $\text{CaCO}_3$ . Very little soil wetting was evident below the 2.3 m depth.

Irrigation water intake during the first application after moldboard plowing to the 0.2 m check depth in 1990 and 1991 is presented in Fig. 3 -- for comparison with results of Musick et al. (1981) after moldboard plowing to 0.2 m in 1975 and 1978; and for comparison with the average of 66 irrigations between 1966 and 1979 that represent present conditions of surface-layer soil consolidation. Intake amounts 25 yr after deep plowing were similar to those after 9 to 12 yr. The difference was slightly less for the 0.6- and 0.8-m plow depths in 1990. Intake after 25 yr remained 30 to 40% higher than when only surface tillage was done from 1966 to 1979.

#### ***Infiltrometer Tests and Hydraulic Conductivity***

Infiltration rates and 8 h cumulative infiltration, as measured by flowing furrow infiltrometer, are presented in Fig. 4a and 4b for 0.2-, 0.4-, and 0.6-m plow depths. The effect of furrow wheel traffic upon infiltration is presented for the 0.2 and 0.4 m plow depths. Infiltration rates were relatively high, ranging from 100 to 180 mm/h until soil shrinkage cracks were filled. Then, infiltration rates were reduced to the 20 to 45 mm/h range after about 1 h.

Traffic effects on infiltration are more apparent from the 8 h cumulative infiltration curves than from infiltration rate curves. Infiltration from both 0.2- and 0.4-m plow depths with wheel traffic were similar, indicating that surface-layer compaction in the furrow controlled intake. Traffic reduced 8 h infiltration by about 23% on the 0.2 m check and about 43% on the 0.4 m plow depth. Compaction by wheel traffic in furrows increases bulk density with the effect extending to about 150 mm below the furrow on this soil as reported by Allen and

Schneider (1992). Using non-traffic furrows on the 0.2 m plow depth (check) as a basis for comparison, 0.4- and 0.6-m plow depths increased infiltration by 66 and 86 mm or 41 and 54%, respectively.

Aronovici and Schneider (unpublished annual report) measured hydraulic conductivity (HC) through undisturbed cores on Pullman clay loam at Bushland and found two zones of very restricted permeability in the B horizon. These occurred at the 0.2 to 0.4 m and the 1.1 to 1.3 m depths (Fig. 5) where HC values declined to about 1.0 mm/h. The relatively sharp increase in HC near the 1.5 m depth occurs at the top of the caliche layer which has visual indications of high macro porosity.

#### ***Soil Water Depletion, ET, Grain Yield, and WUE***

The depletion of soil water from the pre-season irrigation on October 10, 1990, to harvest in June 1991 is presented in Fig. 6 for the 3rd crop yr when growing season precipitation was 207 mm or 80% of average. The wheat crop extracted soil water to about 1.5 m in depth. Soil water storage below the 1.0 m depth for the 0.6 and 0.8 m plow depth treatments was slightly higher than for the 0.4 m depth.

Seasonal ET, grain yield, and WUE are presented in Table 2. Because of increased total irrigation intake and profile depletion with increasing plow depth, ET was also increased with plow depth. Both grain yield and WUE were significantly increased by increasing plow depth from 0.2 to 0.4 m in yr 3 and 4, however deeper plowing to 0.6 and 0.8 m had only minor effect on grain yield and WUE. Our average seasonal ET, 600 to 670 mm, was slightly lower than the average 733 mm reported by Musick et al. (1994) for 6.1 Mg/ha yields obtained from adequate irrigation treatments in 14 yr of field irrigation studies conducted on nearby sites.

Grain yields of 3.6 to 4.3 Mg/ha in yr 2 were about 20% below those for yr 3 and 4. The yield reduction in yr 2 was caused by relatively low fall tillering plus high temperatures and ET during late season grain filling.

## **DISCUSSION**

It is apparent that periodic loosening to the 0.2 m soil depth restores much of the higher intake achieved 25 yr earlier by the inversion-mixing action of moldboard plowing into the dense B21t subsoil. The implications are that one-time deep mixing of soils with slowly permeable layers can provide continued benefit in

irrigation water intake for many years with proper surface-layer soil management. The improved permeability increases the depth and amount of soil water storage and the improved physical condition increases rooting depth to take advantage of deeper soil water storage as reflected by increased extraction with depth. The result is a significant increase in grain yield where one-time moldboard plowing to 0.4 m is performed. This yield increase also can result in higher WUE.

Beginning a winter wheat crop season with a wet profile is a desirable management practice. The deep profile reserve can reduce irrigation requirements in the spring when there is conflict with demands for preplant/emergence irrigations of summer row crops. Since 400 to 800 m row lengths are common for graded furrows, the intake opportunity time on the upper two-thirds to three-fourths of fields is adequate to rewet the soil to about the 0.9 m depth. Thus, deep tilling the upper portions of fields is usually not necessary. A practice with some graded furrow irrigators on slowly permeable clays has been to moldboard plow to about the 0.3 m depth every 3rd yr. A more effective management practice would be to perform deep tillage to about a 0.4 m depth on about the lower one-fourth of a field yearly. The increased intake rates can compensate for reduced lower field section opportunity time. This practice can limit the duration and amount of tailwater runoff.

To maintain the surface-layer soil physical condition, the common producer practice of shallow disking to about 0.12 m is not as effective as moldboard plowing to 0.2 m. The cumulative infiltration curves in Fig. 4b (from infiltrometer tests) illustrate the major effect of both deeper than normal tillage upon intake during the first irrigation after primary tillage. The impact of furrow wheel traffic on irrigation advance and intake is less in producers fields where wider equipment is used. Two wheel tracks per pass of 8 or 12 row equipment only compacts 17 to 25% of furrows compared with 50% of the furrows being compacted on these research plots.

Producers have the opportunity to use readily available agricultural tillers and power units to invert or loosen dense subsoil below normal tillage depth, rather than leasing or purchasing relatively heavy equipment for a one-time operation. These tillers include reversible moldboard plows, bent-leg tillers, and subsoilers that can operate from 0.35 to 0.4 m in depth.

## **CONCLUSIONS**

1. The very long-term (25 yr) residual effect from a one-time vertical mixing of the A and B soil horizons by deep moldboard plowing significantly increased irrigation water intake after annual primary tillage. This increase averaged 26 and 40%, respectively, for 0.4 and 0.6 m initial deep plowing depths compared with the 0.2 m plowed check.
2. The most significant incremental irrigation intake response was for the 0.4 m deep plowing treatment which increased average grain yield by 18% and water use efficiency by 10% compared with the 0.2 m plowed check.
3. Soil surface consolidation caused by successive irrigations, precipitation, and cultural operations; reduced the irrigation intake effect later in the season, however this can readily be restored) by annually moldboard plowing the A soil horizon (top soil) to the 0.2 m depth of the check.
4. Without annual loosening of the A horizon, soil surface conditions rather than subsoil permeability, control irrigation intake.

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**Table 1. Moldboard plow, planting, irrigation, and harvest dates, Bushland, TX.**

Year	0.2m plow	Plant date	Irrigation Dates		Harvest
			Preseason	Seasonal	
1988-89	9/6	10/4	9/14 prepl.	3/14, 5/1	Hail
1989-90	*	9/26	11/7 postpl.	5/7, 5/22	6/21
1990-91	9/15	9/27	10/18 postpl.	4/9, 5/14	6/25
1991-92	9/1	10/1	9/19 prepl.	3/25, 4/28	6/28

\* Moldboard plowing was not performed because of wet soil.

Table 2. Treatment effects on irrigation water intake, ET, yield, and WUE, Bushland, TX.

Crop year	1966 Till depth m	Irrigation Intake				ET mm	Grain Yield Mg ha <sup>-1</sup>	WUE kg m <sup>-3</sup>
		Pre- season mm	Seasonal		Season precip mm			
		1st mm	2nd mm	Total mm				
1988-89	0.2	124b*	112b	76b	312c	**	**	**
	0.4	138b	137a	87ab	362b	-	-	-
	0.6	170a	142a	88ab	400ab	-	-	-
	0.8	173a	150a	95a	418a	-	-	-
1989-90	0.2	126b	80b	61a	267b	132	3.65b	0.65a
	0.4	145ab	83ab	65a	293ab		4.02ab	0.69a
	0.6	147ab	94ab	67a	308a		4.32a	0.72a
	0.8	154a	96a	71a	321a		4.35a	0.72a
1990-91	0.2	135b	147b	116b	398c	207	4.33b	0.70b
	0.4	171a	154ab	128ab	453b		5.56a	0.80a
	0.6	184a	159ab	141a	484ab		5.71a	0.75ab
	0.8	188a	175a	146a	509a		5.64a	0.72b
1991-92	0.2	127c	112a	97a	336c	448	4.73b	0.75b
	0.4	172b	115a	97a	384b		5.37a	0.83a
	0.6	212a	121a	101a	434a		5.28a	0.81ab
	0.8	221a	126a	108a	455a		5.37a	0.81ab

\* Variables followed by the same letter in individual years are not significantly different at the 0.05 level of probability.

\*\* 1989 crop destroyed by hail and soil water related data are not reported.

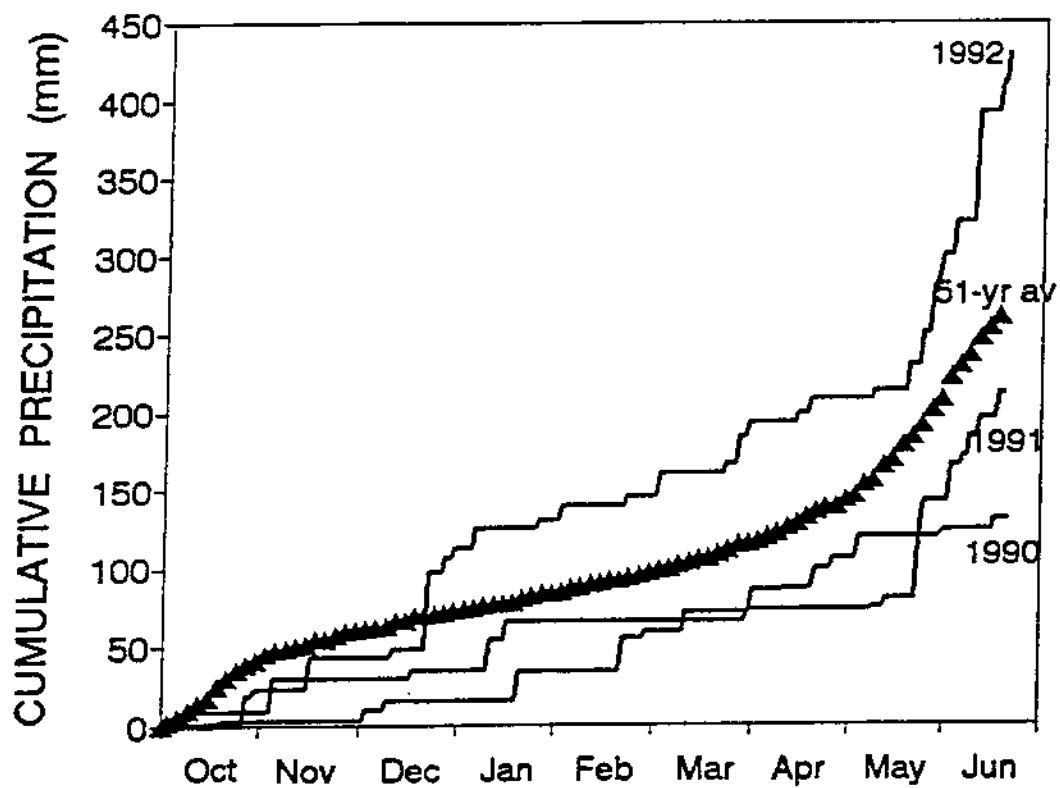


Fig. 1. Cumulative precipitation during 1990-1992 winter wheat growing seasons compared with 51-yr average, Bushland, TX.

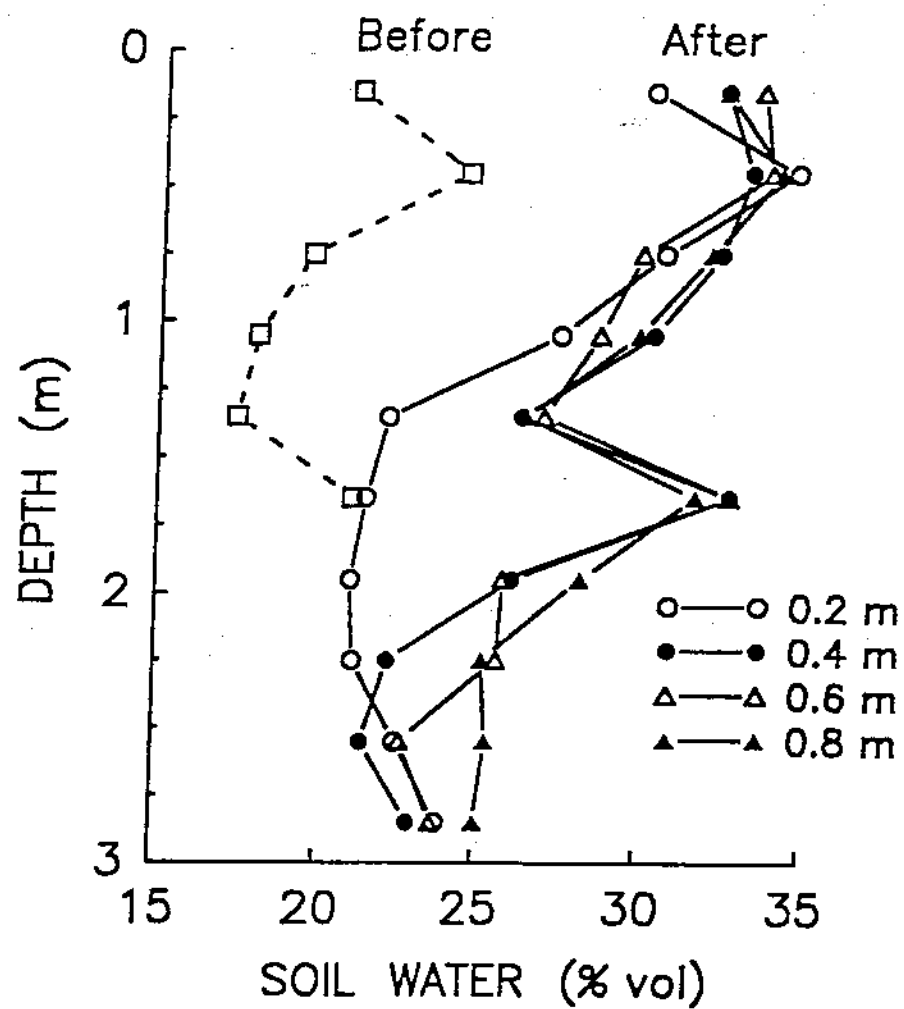


Fig. 2. Residual deep tillage effect on soil water contents with depth following preplant irrigation on 9 Sept. 1988 and a 125 mm rain after irrigation.

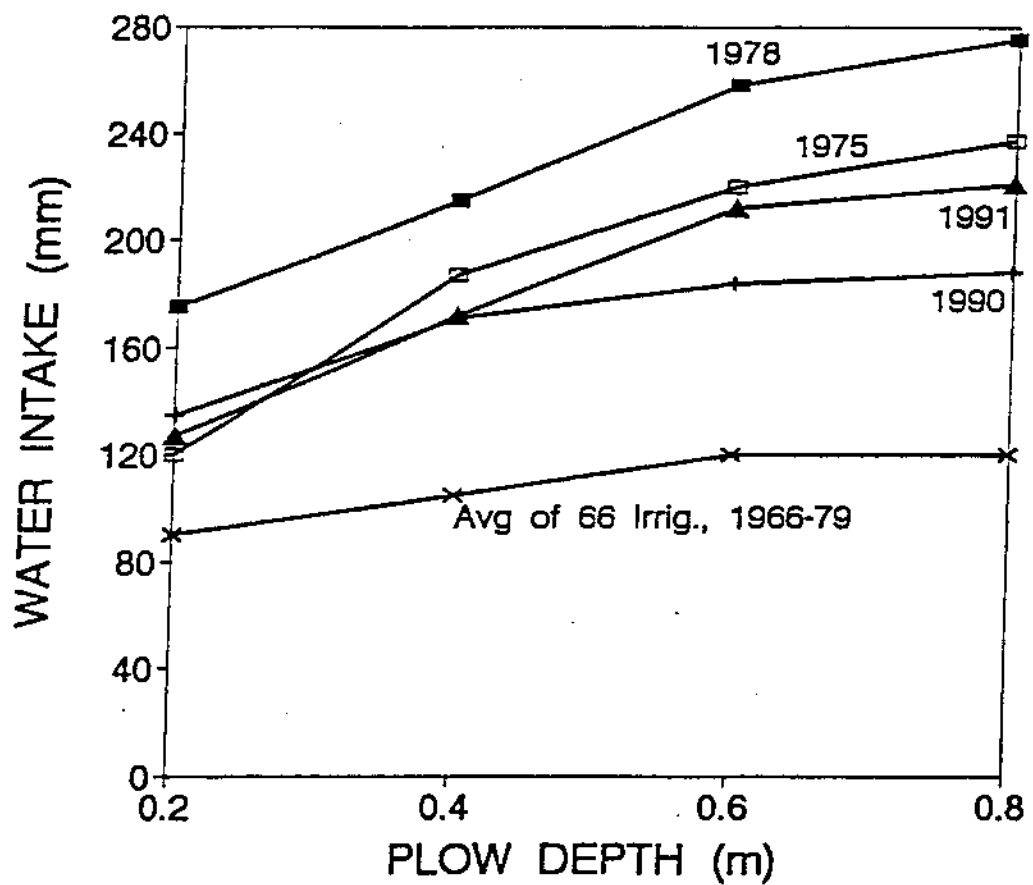


Fig. 3. The long term intake effects for loosened surface-layer condition following moldboard plowing to 0.2 m, are compared with long-term average effects from all investigations which mostly represent consolidated surface-layer soil conditions.

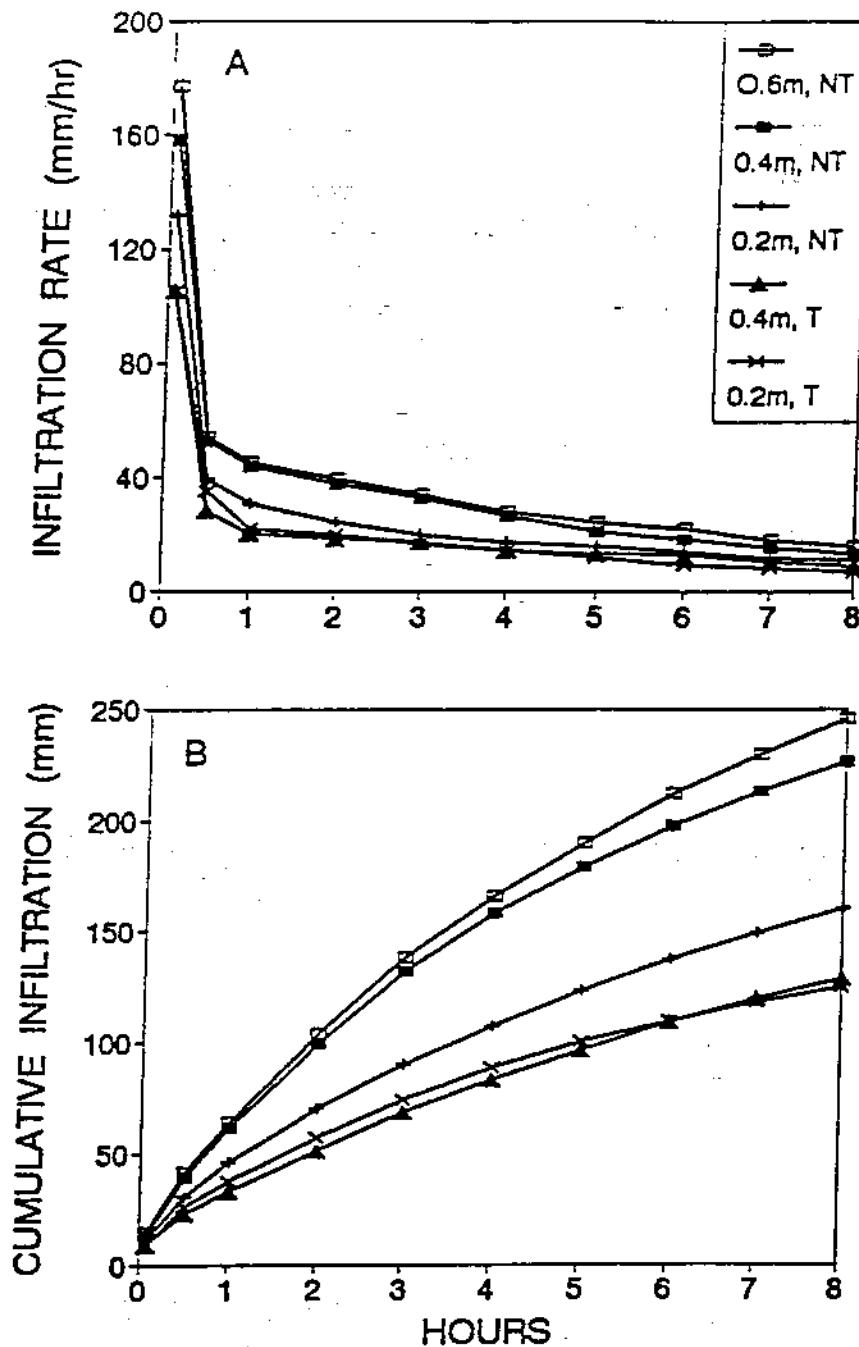


Fig. 4.

Infiltration measured by flowing furrow infiltrometer during 8-h tests for three moldboard plowing treatment depths including comparative traffic (T) and no-traffic furrows (NT), presented as infiltration rates in graph "A" and cumulative infiltration in graph "B".

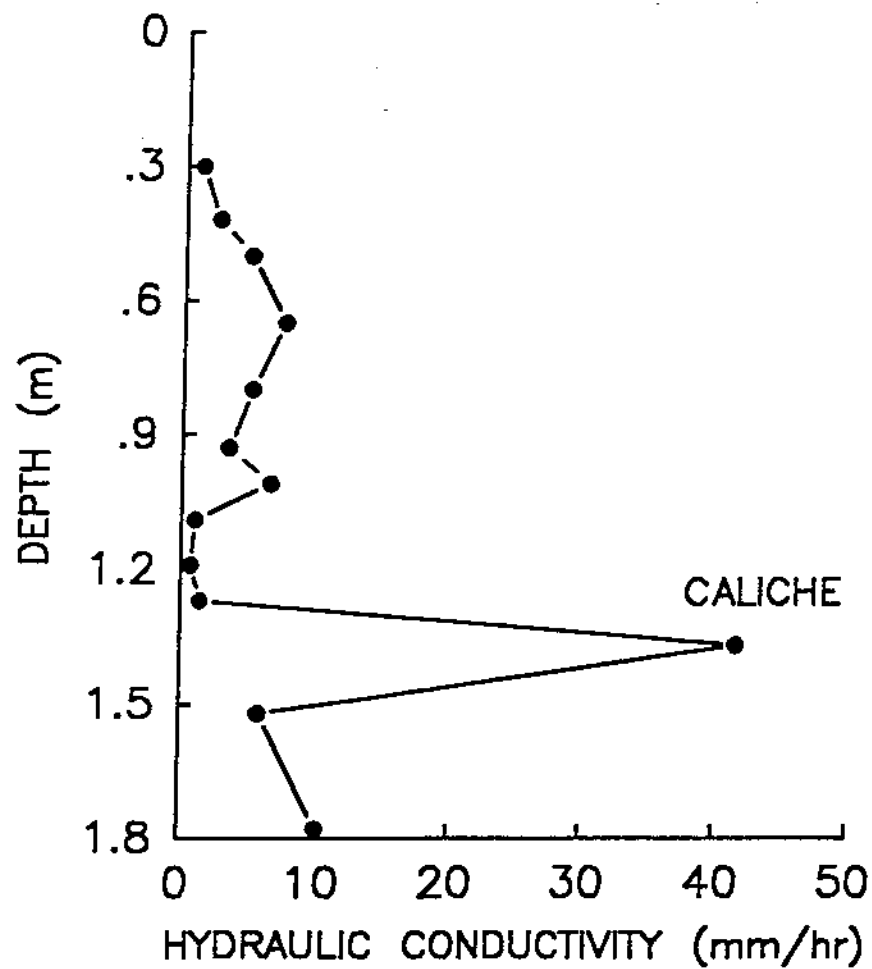


Fig. 5. Hydraulic conductivity with depth of Pullman clay loam through undisturbed cores in 1969 (data from annual report, USDA Southwestern Great Plains Research Center, Bushland, TX, by Aronovici and Schneider).

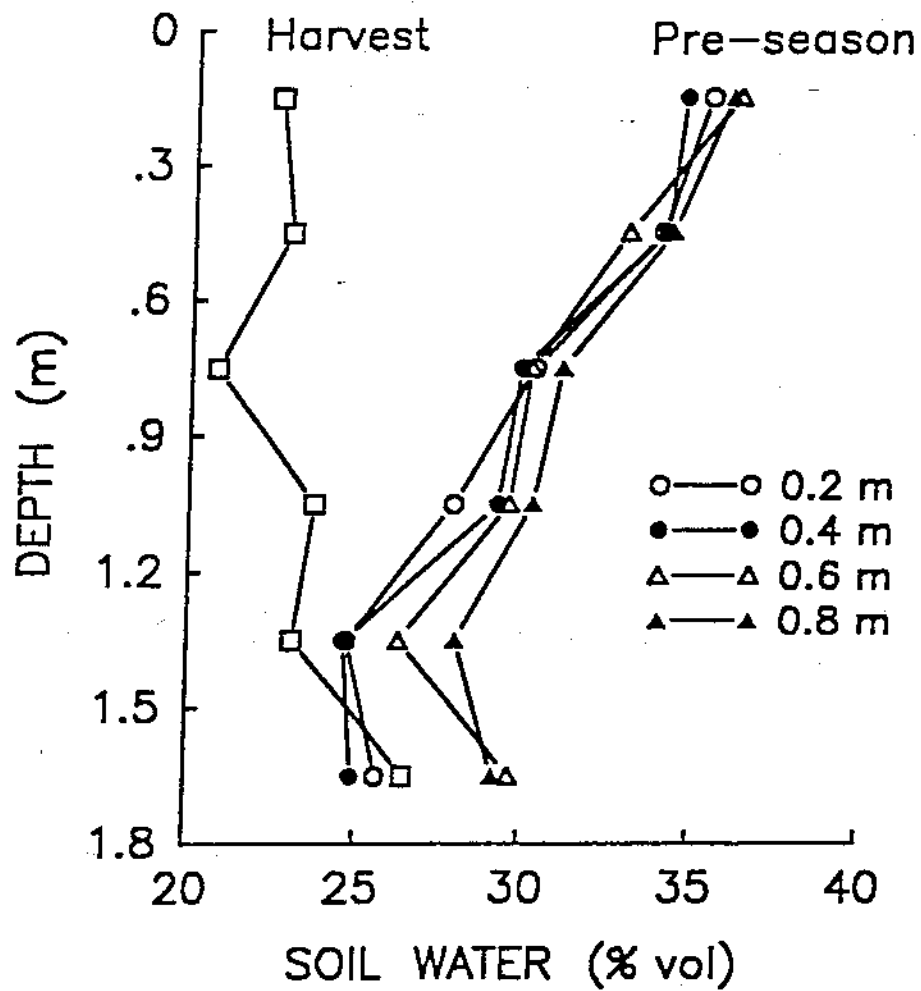


Fig. 6. Depletion of soil water with depth for deep plowing treatments following a pre-season irrigation on 18 Oct. 1990 until harvest on 25 June 1991.